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CHAPTER 8: FLOW RECOMMENDATIONS FOR THE RECOVERY OF ENDANGERED FISHES

Mimicry of the natural hydrograph is the foundation of the flow recommendation process for the San Juan River. The linkages between hydrology, geomorphology, habitat, and biology were used to define mimicry in terms of flow magnitude, duration, and frequency for the runoff and base flow periods. The flow characteristics of these linkages were compared with the statistics of the pre-Navajo Dam hydrology to assist in fine-tuning the recommendations. The flow recommendations require mimicry of statistical parameters of flow based on the linkages developed and the statistical variability of the pre-dam hydrology rather than mimicry of each annual hydrograph. A 65-year period of record (1929 to 1993) was used to assess the relationship between water development scenarios and the ability to meet the flow recommendations.

The flow recommendations are made in two parts. The first part contains the conditions of the hydrograph that will promote endangered fish recovery. These flow/duration/frequency recommendations will result in a naturally varying hydrograph, providing high-flow and low-flow years. These recommendations also provide for adequate base flow conditions and peak flow conditions of sufficient magnitude, duration, and frequency to provide suitable conditions for the endangered species. They can be achieved by using the operating criteria for Navajo Dam outlined in the second part of this chapter. By recommending operating rules, natural variability in the hydrograph is maintained and decision making for annual releases from Navajo Dam is simplified. Results of the flow recommendations on future water development is discussed in the third part of this chapter.

These flow recommendations are based on the best available information at this time given the present status of the two endangered fish species. These recommendations are not final, however, because there are still life stages of the two endangered species that have not been studied in the San Juan River because of low fish numbers, and additional information may be gathered in the future. Therefore, these recommendations may be altered through the adaptive management program envisioned in Section 5.7 of the LRP. Adaptive management will allow for refinement of these recommendations as fish populations increase or as water depletion in the basin changes. It is recommended that the model and flow recommendations be reviewed by the SJRIP at least every 5 years, thus keeping the model as an accurate working tool for basin fish recovery and water development.

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RECOMMENDED HYDROGRAPH CONDITIONS

This chapter discusses the results of operating the model with the hypothetical development scenarios discussed in Chapter 7 and for a variety of hydrologic parameters that make up the flow recommendations. As summarized in Chapter 6, flows of 2,500, 5,000, 8,000, and 10,000 cfs were important to create or maintain various habitats used by the native fishes or to maintain habitat complexity. These flow levels also provide a reasonable spectrum of flows to use in defining mimicry of a natural hydrograph. Several model iterations were completed to determine various hydrologic and habitat implications. These iterations were reviewed by the Biology Committee and were refined as additional information developed and as deemed appropriate by committee members' professional opinions. Using the information available, the goal of this process was to develop the most accurate flow recommendations to aid the recovery of the endangered fish species, recognizing that continued water development in the basin was also a goal of the SJRIP.

These hydrograph recommendations are designed to meet the conditions required to develop and maintain habitat for Colorado pikeminnow and razorback sucker, and to provide the necessary hydrologic conditions for the various life stages of the endangered and other native fishes. The conditions are listed in terms of flow magnitude, duration (days at or above specified magnitude), and frequency (average recurrence of the conditions specified, expressed as a percent and a maximum allowable duration of years without meeting the condition). To allow for the difference between the flows at the historical gage at Bluff, Utah, and the Four Corners gage used for modeling, maximum allowable durations are computed for 97% of the target flow rate. In most cases, the primary recommendation is for a specified flow rate (i.e., 10,000 cfs) of a minimum duration (i.e., 5 days) for a specific frequency of occurrence (i.e., 20% of the time). Duration is determined as the number of days that the specified flow magnitude is equaled or exceeded during the spring runoff period of March 1 to July 31. Frequency is the average recurrence of the conditions specified (magnitude and duration), expressed as a percent of the 65 years of record analyzed (1929 to 1993). The underlying assumption in the flow conditions is that, over a long period of time, history will repeat itself: if the conditions were met during the past 65 years, they will also be met in the future. To the extent that the water supply is different in the future, then the natural condition would also be altered and the conditions of mimicry would be maintained, although the exact flow recommendation statistics may not be met.

In addition to the primary recommendation, variability in duration is desirable to mimic a natural hydrograph. Therefore, a frequency table (Table 8.1) for a range of durations for each flow rate is recommended. A maximum duration between occurrences is also specified to avoid long periods when conditions are not met, as such long periods could be detrimental to the recovery of the species. The maximum period without reaching a specified condition was determined as twice the average required interval (except for the 80% recurrence of the 2,500-cfs condition, where 2 years is used). For example, if the average interval is 1 year in 3, then the maximum period between meeting conditions would be 6 years. The maximum periods were based on the collective judgment of Biology Committee members after review of historical pre-dam statistics. The biological basis of the recommendations is summarized in Chapter 6. The recommendations are based on statistics

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Table 8.1. Frequency distribution table for flow/duration recommendations.

Duration	Discharge			
	>10,000 cfs	>8,000 cfs	>5,000 cfs	>2,500 cfs
	Minimum Average Frequency for Period of Record			
1 day	30%	40%	65%	90%
5 days	20%	35%	60%	82%
10 days	10%	33%	58%	80%
15 days	5%	30%	55%	70%
20 days		20%	50%	65%
30 days		10%	40%	60%
40 days			25%	50%
50 days			20%	45%
60 days			15%	40%
80 days			5%	25%

Note: Primary criteria are shown in shaded cells.

for the 1929 to 1993 period, assuming that Navajo Dam was in place and reoperated according to the recommendations of this chapter. Those statistics are evaluated against the 1929 to 1961 pre-dam conditions.

Following are the conditions of the flow recommendations:

A. Category: Flows > 10,000 cfs during runoff period (March 1 to July 31).

Duration: **A minimum of 5 days between March 1 and July 31**.

Frequency: **Flows > 10,000 cfs for 5 days or more need to occur in 20% of the years on average for the period of record 1929 to 1993**. Maximum number of consecutive years without meeting at least a flow of 9,700 cfs (97% of 10,000 cfs) within the 65-year period of record is 10 years.

Purpose: Flows above 10,000 cfs provide significant out-of-bank flow, generate new cobble sources, change channel configuration providing for channel diversity, and provide nutrient loading to the system, thus improving habitat productivity. Such flows provide material to develop spawning habitat and maintain channel diversity and habitat complexity necessary for all life stages of endangered fishes. The frequency and duration are based on mimicry of the natural hydrograph, which is important for Colorado pikeminnow

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reproductive success and maintenance of channel complexity, as evidenced by the increase in the number of islands following high-flow conditions. Channel complexity is important to both Colorado pikeminnow and razorback sucker.

B. Category: Flow > 8,000 cfs during runoff period.

Duration: **A minimum of 10 days between March 1 and July 31**.

Frequency: **Flows > 8,000 cfs for 10 days or more need to occur in 33% of the years on average for the period of record 1929 to 1993**. Maximum number of consecutive years without meeting at least a flow of 7,760 cfs (97% of 8,000 cfs) within the 65-year period of record is 6 years.

Purpose: Bankfull discharge is generally between 7,000 and 10,500 cfs in the San Juan River below Farmington, New Mexico, with 8,000 cfs being representative of the bulk of the river. Bankfull discharge approximately 1 year in 3 on average is necessary to maintain channel cross-section. Flows at this level provide sufficient stream energy to move cobble and build cobble bars necessary for spawning Colorado pikeminnow. Duration of 8 days at this frequency is adequate for channel and spawning bar maintenance. However, research shows a positive response of bluehead sucker and speckled dace abundance with increasing duration of flows above 8,000 cfs from 0 to 19 days. Therefore, the minimum duration was increased from 8 to 10 days to account for this measured response. Flows above 8,000 cfs may be important for providing habitat for larval razorback sucker if flooded vegetation and other habitats formed during peak and receding flows are used by the species. This flow level also maintains mimicry of the natural hydrograph during higher flow years, an important feature for Colorado pikeminnow reproductive success.

C. Category: Flow > 5,000 cfs during runoff period.

Duration: **A minimum of 21 days between March 1 and July 31**.

Frequency: **Flows > 5,000 cfs for 21 days or more need to occur in 50% of the years on average for the period of record 1929 to 1993**. Maximum number of consecutive years without meeting at least a flow of 4,850 cfs (97% of 5,000 cfs) within the 65-year period of record is 4 years.

Purpose: Flows of 5,000 cfs or greater for 21 days are necessary to clean backwaters and maintain low-velocity habitat in secondary channels in Reach 3, thereby maximizing nursery habitat for the system. The required frequency of these

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flows is dependent upon perturbating storm events in the previous period, requiring flushing about 50% of the years on average. Backwaters in the upper portion of the nursery habitat range clean with less flow but may be too close to spawning sites for full utilization. Maintenance of Reach 3 is deemed critical at this time because of its location relative to the Colorado pikeminnow spawning area (RM 132) and its backwater habitat abundance.

D. Category: Flow >2,500 cfs during runoff period.

Duration: **A minimum of 10 days between March 1 and July 31**.

Frequency: **Flows > 2,500 cfs for 10 days or more need to occur in 80% of the years on average for the period of record 1929 to 1993**. Maximum number of consecutive years without meeting at least a flow of 2,425 cfs (97% of 2,500 cfs) within the 65-year period of record is 2 years.

Purpose: Flows above 2,500 cfs cause cobble movement in higher gradient areas on spawning bars. Flows above 2,500 cfs for 10 days provide sufficient movement to produce clean cobble for spawning. These conditions also provide sufficient peak flow to trigger spawning in Colorado pikeminnow. The frequency specified represents a need for frequent spawning conditions but recognizes that it is better to provide water for larger flow events than to force a release of this magnitude each year. The specified frequency represents these tradeoffs.

E. Category: Timing of the peak flows noted in conditions A through D above must be similar to historical conditions, and the variability in timing of the peak flows that occurred historically must also be mimicked.

Timing: Mean date of peak flow in the habitat range (RM180 and below) for any future level of development when modeled for the period of 1929 to 1993 must be within 5 days ± of historical mean date of May 31 for the same period.

Variability: Standard deviation of date of peak to be 14 to 25 days from the mean date of May 31.

Purpose: Maintaining similar peak timing will provide ascending and descending hydrograph limbs timed similarly to the historical conditions that are suspected important for spawning of the endangered fishes.

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F. Category: Target Base Flow (mean weekly nonspring runoff flow).

Level: 500 cfs from Farmington to Lake Powell, with 250 cfs minimum from Navajo Dam.

Purpose: Maintaining low, stable base flows enhances nursery habitat conditions. Flows between 500 and 1,000 cfs optimize backwater habitat. Selecting flows at the low end of the range increases the availability of water for development and spring releases. It also provides capacity for storm flows to increase flows and still maintain optimum backwater area. This level of flow balances provision of near-maximum low-velocity habitat and near-optimum flows in secondary channels, while allowing water availability to maintain the required frequency, magnitude, and duration of peak flows important for Colorado pikeminnow reproductive success.

G. Category: Flood Control Releases (incorporated in operating rule).

Control: Handle flood control releases as a spike (high magnitude, short duration) and release when flood control rules require, except that the release shall not occur earlier than September 1. If an earlier release is required, extend the duration of the peak of the release hydrograph. A ramp up and ramp down of 1,000 cfs per day should be used to a maximum release of 5,000 cfs. If the volume of water to release is less than that required to reach 5,000 cfs, adjust the magnitude of the peak accordingly, maintaining the ramp rates. Multiple releases may be made each year. These spike releases shall be used in place of adjustments to base flow.

Purpose: Historically, flood control releases were made by increasing fall and winter base flows. This elevates flows above the optimum range for nursery habitat. Periodic clean-water spike flows improve low-velocity habitat quality by flushing sediment and may suppress red shiner and fathead minnow abundance.

RECOMMENDED RESERVOIR OPERATING RULES

Mimicry of a natural hydrograph requires maintenance of variability in the hydrograph while maintaining the recommended flows in the San Juan River below Navajo Dam. The following operating rules allow for these conditions to be met. The rules were developed in cooperation with the Bureau, which operates the dam. The rules function within the context of the available water in a given year and what has occurred in previous years, providing for a dynamic flow regime over a period of years as well as within any single year. The rules are based on numerous model runs for real and hypothetical water development conditions ranging from 609,000 af of depletion

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(approximate current level of development, not including Dolores Project return flows) to 1,008,000 af of depletion (depletion base + 280,000 af). As noted in Chapter 7, the use of these hypothetical water development scenarios does not imply any right to develop, any priority of development, or priority of Consultation. Neither do these scenarios attempt to exclude others from developing. Each of the parameters has been tested for a range of values, and the conditions recommended to provide the closest match to the desired hydrograph conditions over the development range.

Sensitivity analysis demonstrated that the conditions of the flow recommendation and the goals for continuation of water development could best be met by maintaining a peak release from Navajo Dam of 6,000 cfs. Studies conducted by the Bureau and the Corps in 1998 indicated that the channel capacity and the dam outlet works capacity may not be sufficient to allow a release of this magnitude. It was concluded that additional studies would be required before dam releases could be increased above 5,000 cfs. Therefore, operating rules have been developed that include both 5,000-cfs and 6,000-cfs peak release. If the actual channel and release capacity is between 5,000 and 6,000 cfs, the rules can be adjusted to match the determined capacity.

Figures 8.1 and 8.2 are flow charts showing the process that could be used by the Bureau to determine the magnitude and timing of flow releases from Navajo Dam. The first decision to be made is whether or not there is sufficient water for a peak release. If there is sufficient water (> 114,000 af), then the magnitude of the release is determined. The minimum peak release of about 114,000 af would provide a release peak for 1 week. The primary peak release provides a peak release flow for 3 weeks. The actual flow in the river below the mouth of the Animas River will depend on the flow in the Animas River during the peak release from Navajo Dam. In addition to the amount of water available (through precipitation forecasts in the spring), the history of recent peak releases also is important in determining the size and timing of a peak release.

In describing the operating conditions, the definitions of several terms are specific to this flow recommendation. In defining release hydrographs, two conditions are described. The minimum peak release specifies the release conditions that would apply in dry years. Releases smaller than this have shown to be detrimental to nursery habitat because they produce flows below the threshold necessary for backwater cleaning and they allow sediment berms to form in the mouths of backwaters. The primary peak release has the most desirable shape and magnitude characteristics, given adequate water availability. When the water supply allows a release volume between the minimum and primary peak releases, the conditions for adjusting the hydrograph are specified accordingly to optimize the utility of the release. In some wet years, water in excess of the primary peak release must be released in order to prevent reservoir spills and downstream flooding. The impacts to the endangered fishes, their habitat, and the need to safely operate Navajo Dam were taken into consideration when developing the conditions given for releasing excess water.

The decision to make a release of a given magnitude, or to store water for a larger future release, is related to the condition of the nursery habitat. If the nursery habitat has been affected by sediment-laden storm events, it would be considered a perturbation year. A perturbation year will be determined from the results of the monitoring program, and the results will be provided to the

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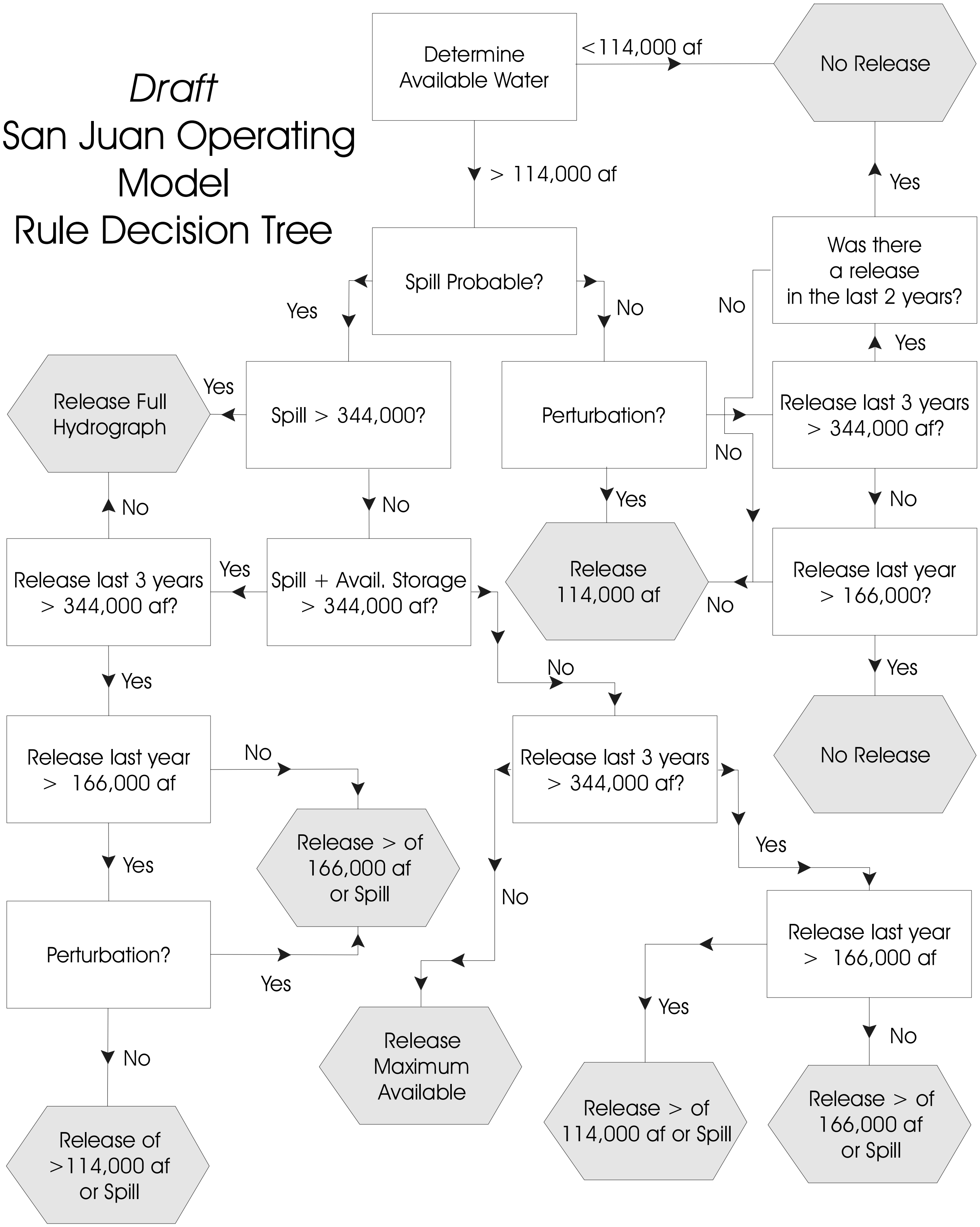

Figure 8.1. Flow chart of Navajo Dam operating rules for a 5,000-cfs peak release.

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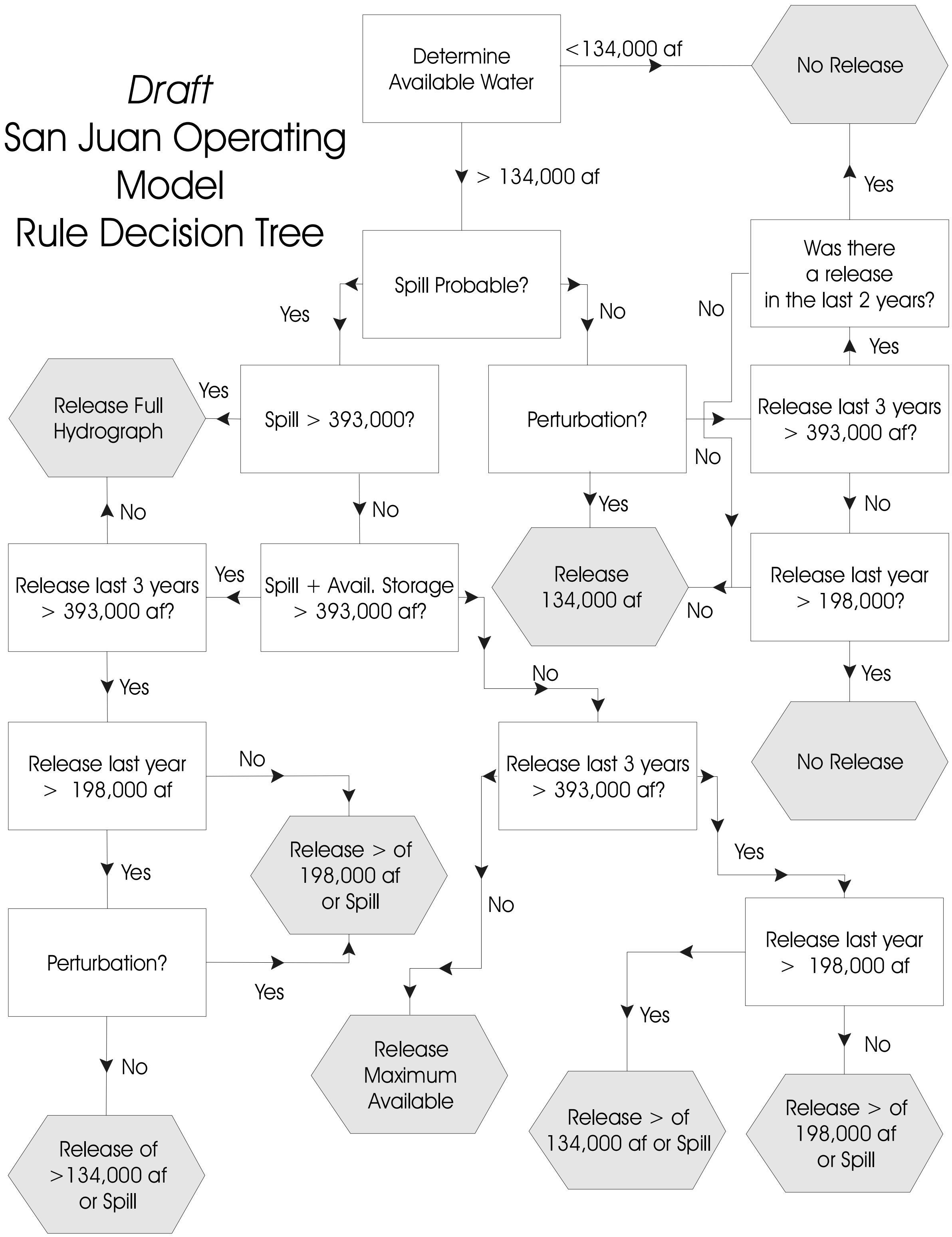

Figure 8.2. Flow chart of Navajo Dam operating rules for a 6,000-cfs peak release.

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Bureau by the SJRIP in January of each year for inclusion in the decision-making process. In the absence of a direct observation, a perturbation year will be declared if there are more than 13 storm event days as defined on page 7-3 between August 1 and December 31.

In the following rules, the first value given relates to a 5,000-cfs peak and the second to a 6,000-cfs peak.

- Minimum peak release consists of 1 week ramp up to 5,000 to 6,000 cfs, 1 week at 5,000 to 6,000 cfs, and 1 week ramp down. Daily flow rates for ramping are given in Table 8.2 for 5,000 cfs and in Table 8.3 for 6,000 cfs. Volume is 114,000 to 134,000 af above average base release of 600 cfs.

- Primary peak release hydrograph consists of 4 week ramp up to 5,000 to 6,000 cfs, 3 weeks at 5,000 to 6,000 cfs, and 2 weeks ramp down. Ramp rates are given in Table 8.2 for 5,000 cfs and in Table 8.3 for 6,000 cfs. Volume is 344,000 to 393,000 af above average base release of 600 cfs.

- Median peak on the Animas River is June 1. No correlation between volume or runoff magnitude and peak date exists. Sensitivity analysis indicates the best results are achieved with a peak release from Navajo Dam centered on June 4 for a 5,000-cfs peak release and June 2 for a 6,000-cfs peak release. Fix the center of the 5,000-cfs release on June 4 and the center of the 6,000-cfs release on June 2 every year.

- Use the attached decision tree (Figure 8.1 for 5,000 cfs and Figure 8.2 for 6,000-cfs peak release) to determine magnitude of release. Available water on the chart is defined as: *"predicted inflow less base release plus available storage*," where available storage is reduced from full storage by the amount of carry-over storage necessary to prevent shortages in future years and all storage volumes include inactive storage. "*Release last 3 years > 393,000 af,*" means that a release of at least 393,000 af occurred during at least 1 out of the last 3 years. Table 8.4 lists the model calibrated values for carry-over storage to be used in this calculation for a development range. When new development is proposed, the model should be operated to verify the value to be used.

- In years when the spill is predicted to be greater than 344,000 to 393,000 af, adjust the hydrograph by first adding an earlier release of 2,000 cfs to the front of the ascending limb and extending it to as early as March 1. Increase this early release by 500 cfs and increment calculation of duration until time extension is March 1, if necessary, to use all of the release flow volume computed by application of Figures 8.1 or 8.2. Ramp up on the beginning of the early release from base flow cannot exceed 1,000 cfs per day.

Table 8.2. Recommended daily ramp rates for 1-week, 2-week, 3-week, and 4-week ramps for a 5,000-cfs peak release.

DAY	FLOW RATE (cfs)			
	1 WEEK	2 WEEK	3 WEEK	4 WEEK
1	1,000	1,000	1,000	1,000
2	1,500	1,000	1,000	1,000
3	2,000	1,500	1,000	1,000
4	2,500	1,500	1,000	1,000
5	3,000	2,000	1,500	1,000
6	3,500	2,000	1,500	1,000
7	4,000	2,500	1,500	1,000
8	5,000	2,500	2,000	2,000
9		3,000	2,000	2,000
10		3,000	2,000	2,000
11		3,500	2,000	2,000
12		4,000	3,000	2,000
13		4,000	3,000	2,000
14		4,500	3,000	2,000
15		5,000	3,000	3,000
16			4,000	3,000
17			4,000	3,000
18			4,000	3,000
19			4,000	3,000
20			4,000	3,000
21			4,000	3,000
22			5,000	4,000
23				4,000
24				4,000
25				4,000
26				4,000
27				4,000
28				4,000
29				5,000

Table 8.3. Recommended daily ramp rates for 1-week, 2-week, 3-week, and 4-week ramps for a 6,000-cfs peak release.

DAY	FLOW RATE (cfs)			
	1 WEEK	2 WEEK	3 WEEK	4 WEEK
1	1,000	1,000	1,000	1,000
2	1,500	1,000	1,000	1,000
3	2,000	1,500	1,000	1,000
4	2,500	1,500	1,000	1,000
5	3,000	2,000	1,500	1,000
6	4,000	2,500	1,500	1,000
7	5,000	2,500	1,500	1,000
8	6,000	3,000	2,000	2,000
9		3,000	2,000	2,000
10		3,500	2,000	2,000
11		4,000	2,000	2,000
12		4,000	3,000	2,000
13		4,500	3,000	2,000
14		5,000	3,000	2,000
15		6,000	4,000	3,000
16			4,000	3,000
17			4,000	3,000
18			4,000	3,000
19			4,000	3,000
20			4,000	3,000
21			5,000	3,000
22			6,000	4,000
23				4,000
24				4,000
25				4,000
26				4,000
27				4,000
28				5,000
29				6,000

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Table 8.4. **Minimum carry-over storage for modeled levels of development for use in determination of available water per Figures 8.1 and 8.2.**

DEVELOPMENT LEVEL	CURRENT	DEPLETION BASE	DEPLETION BASE +59,000	DEPLETION BASE +122,000	DEPLETION BASE +210,000	DEPLETION BASE +280,000
Carry-over Storage for 5,000 cfs (af)	900,000	1,000,000	1,288,200	1,453,200	1,700,000	1,700,000
Carry-over Storage for 6,000 cfs (af)	900,000	1,000,000	1,125,500	1,453,200	1,700,000	1,700,000

- In years when the release will be greater than 114,000 to 134,000 af but less that 344,000 to 393,000 af, use the following adjustment rules in this order of selection:

  1. Decrease time of descending limb by as much as 1 week to achieve necessary reduction.

  2. Decrease time of ascending limb by as much as 3 weeks to achieve necessary reduction.

  3. Reduce duration of peak by as much as 2 weeks.

  4. Ramping rates are shown in Tables 8.2 and 8.3 for 5,000- and 6,000-cfs peak releases, respectively. Rates shown are ideal rates and may be adjusted within reasonable limits to accommodate dam operating procedures and flood control requirements. Changes should not exceed 1,000 cfs per day.

- Target base flow (average weekly) following spring peak is 500 cfs at Farmington, Shiprock, Four Corners, and Bluff gages, measured as the average of any two of these gages. Minimum release is 250 cfs. The target flow should be maintained between 500 and 600 cfs, attempting to maintain target flow closer to 500 cfs.

- Handle flood control releases as a spike (high magnitude, short duration) and release when flood control rules require, except the release shall not occur earlier than September 1. If an earlier release is required, extend the peak duration of the release hydrograph. A ramp up and ramp down of 1,000 cfs per day should be used to a maximum release of 5,000 cfs. If the released volume is less than that required to reach 5,000 cfs, adjust the magnitude of the peak accordingly, maintaining the ramp rates. Multiple releases may be made each year. These spike releases shall be used in place of adjustments to base flow.

- In no case shall the reservoir be allowed to fall below the elevation that allows full diversion of water to NIIP.

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These operating rules are presented as recommendations and were used in the modeling process to assess the system's ability to maintain the flow recommendations. Other operating rules may be employed to achieve the desired river conditions specified in this chapter, if the natural variability provided by the rules presented above is maintained.

MODEL RESULTS

Hydrologic Results

Table 8.5 summarizes the hydrologic condition for the six modeled levels of hypothetical development discussed in Chapter 7 with comparisons to historical conditions at the Bluff gage for pre-dam (1929 to 1961), post-dam (1962 to 1991), and study (1992 to 1997) periods for a 5,000-cfs peak release. The same information is shown in Table 8.6 for a peak release of 6,000 cfs. The six modeled conditions use the modeled Four Corners daily flow for the 1929 to 1993 period. The Four Corners gage is used rather than the Bluff gage, since it better represents the average condition in Reaches 4 and 5, important areas for the endangered fishes, and it is upstream of the Dolores Project inflows to McElmo Creek which are problematic in the model. Because of local inflow during the runoff period, the average peak magnitude and volume of the flows at Bluff are about 3% higher than at Four Corners. However, the difference is within gage error, so the comparisons are considered reasonable.

Flow statistics for all levels of development are equal to or better than post-dam conditions for nearly all parameters at all levels of development studied through depletion base plus 280,000 af, demonstrating the negative effect on the hydrograph and habitat as a result of Navajo Dam operation prior to 1992. Compared with pre-dam conditions, all levels of development reduce the peak magnitude and volume of the runoff period flows. Flow/duration conditions, identified as important for habitat development and biological response, show a somewhat different relationship. The frequency of meeting minimum durations of 10,000-cfs flows are better than pre-dam historical conditions for levels of development through the depletion base plus 59,000 af condition with a 6,000-cfs release but for no future condition with a 5,000-cfs release. Frequency for 8,000-cfs minimum durations are better for all levels of development through depletion base plus 122,000 af with a 6,000-cfs peak release, but only through current conditions for a 5,000-cfs release. Frequency for 5,000-cfs minimum durations are better than pre-dam conditions for current depletion levels only, regardless of peak release. Frequency of meeting minimum durations for 2,500- and 5,000-cfs flow recommendations are somewhat reduced for all levels of development. Figures 8.3 through 8.6 show the flow/duration/frequency relationships for flows above 2,500, 5,000, 8,000, and 10,000 cfs, respectively, for a peak release of 5,000 cfs. Figures 8.7 through 8.10 show the same information for a 6,000-cfs peak release.

A major change from pre-dam conditions is the maximum years between meeting flow/duration conditions, partly because the natural peak runoff relative to the earlier record was reduced for the period from 1952 through 1972. All of the maximum intervals between meeting conditions occur

Table 8.5. Comparison of hydrograph statistics for six levels of development and three historical periods for the period 1929 to 1993 for 5,000 cfs peak release.

PARAMETER	PRE-DAM	POST-DAM	RESEARCH PERIOD	CURRENT	DEPLETION BASE	BASE +59,000	BASE +122,000	BASE +210,000	BASE +280,000
Average Peak Runoff - cfs	12,409	6,749	8,772	10,041	9,795	9,403	8,827	7,969	7,438
Average Runoff - af	1,263,890	891,712	1,132,899	1,042,635	963,549	916,510	869,386	790,314	728,215
	Frequency	Frequency	Frequency	Frequency	Frequency	Frequency	Frequency	Frequency	Frequency
Peak>10,000 cfs	55%	20%	33%	43%	43%	43%	42%	32%	32%
Peak>8,000 cfs	67%	37%	83%	77%	72%	68%	62%	52%	45%
Peak>5,000 cfs	91%	53%	83%	97%	97%	88%	77%	65%	57%
Peak>2,500 cfs	100%	90%	100%	100%	100%	98%	97%	91%	88%
AF>1,000,000	55%	40%	67%	42%	40%	35%	34%	31%	28%
AF>750,000	67%	47%	83%	63%	58%	58%	54%	45%	40%
AF>500,000	91%	67%	83%	82%	74%	71%	68%	60%	51%
>10,000 cfs for 5 days	39%	**13%**	33%	35%	34%	31%	31%	23%	22%
>8,000 cfs for 8 days	48%	**27%**	50%	48%	46%	45%	43%	34%	32%
>8,000 cfs for 10 days	45%	**17%**	50%	46%	45%	42%	40%	**32%**	**32%**
>5,000 cfs for 21 days	64%	**37%**	83%	68%	62%	62%	58%	**55%**	**42%**
>2,500 cfs for 10 days	100%	83%	100%	97%	97%	91%	86%	**72%**	**69%**
Maximum years between flow events for minimum duration									
10,000 cfs - 5 days	4	**14**	n/a	6	6	9	9	**14**	**14**
8,000 cfs - 10 days	4	**7**	n/a	6	6	6	6	**14**	**14**
5,000 cfs - 21 days	4	**7**	n/a	3	4	3	4	43	**7**
2,500 cfs - 10 days	0	1	n/a	1	1	2	2	**3**	**4**
Non-corrected Perturbation	12%	27%	0%	17%	18%	18%	22%	23%	28%
Average Date of Peak	31-May	01-Jun	07-Jun	04-Jun	04-Jun	05-Jun	04-Jun	04-Jun	05-Jun
Standard Dev of Peak Date	23 days	35 days	8 days	12 days	12 days	14 days	14 days	16 days	20 days
Days>10,000 cfs	14	3	2	6	5	5	5	4	3
Days>8,000 cfs	23	8	10	16	14	13	13	11	10
Days>5,000 cfs	46	28	51	43	38	35	32	30	26
Days>2,500 cfs	82	67	90	71	65	61	55	50	44
Meets recommendation				yes	yes	yes	yes	no	no

Note: Bold values indicate recommendation not met. Baseline + 280,000 is water short 174,000 af in 1956; 83,000 af in 1957. Maximum years between meeting minimum conditions are computed at 97% of the target flow rate to account for differences between Bluff and Four Corners flows.

Table 8.6. Comparison of hydrograph statistics for six levels of development and three historical periods for the period 1929 to 1993 for 6,000 cfs peak release.

PARAMETER	PRE-DAM	POST-DAM	STUDY PERIOD	CURRENT	DEPLETION BASE	BASE +59,000	BASE +122,000	BASE +210,000	BASE +280,000
Average Peak Runoff - cfs	12,409	6,749	8,772	10,882	10,553	10,502	9,319	8,378	7,738
Average Runoff - af	1,263,890	891,712	1,132,899	1,055,365	973,577	925,841	874,521	793,829	730,812
	Frequency	Frequency	Frequency	Frequency	Frequency	Frequency	Frequency	Frequency	Frequency
Peak>10,000 cfs	55%	20%	33%	48%	45%	46%	43%	40%	32%
Peak>8,000 cfs	67%	37%	83%	89%	83%	80%	65%	57%	49%
Peak>5,000 cfs	91%	53%	83%	97%	95%	92%	75%	60%	55%
Peak>2,500 cfs	100%	90%	100%	100%	100%	98%	98%	91%	88%
AF>1,000,000	55%	40%	67%	49%	40%	35%	35%	31%	28%
AF>750,000	67%	47%	83%	62%	60%	57%	54%	43%	37%
AF>500,000	91%	67%	83%	78%	72%	69%	69%	58%	51%
>10,000 cfs for 5 days	39%	**13%**	33%	43%	42%	40%	37%	34%	26%
>8,000 cfs for 8 days	48%	**27%**	50%	68%	65%	63%	57%	49%	40%
>8,000 cfs for 10 days	45%	**17%**	50%	63%	60%	57%	52%	43%	**35%**
>5,000 cfs for 21 days	64%	**37%**	83%	65%	60%	57%	57%	**52%**	**40%**
>2,500 cfs for 10 days	100%	83%	100%	97%	97%	95%	85%	**69%**	**69%**
Maximum years between flow events for minimum duration									
10,000 cfs - 5 days	4	**14**	n/a	6	9	9	10	**14**	**14**
8,000 cfs - 10 days	4	**7**	n/a	3	4	4	4	**7**	**8**
5,000 cfs - 21 days	4	**7**	n/a	3	4	4	4	4	**7**
2,500 cfs - 10 days	0	1	n/a	1	1	1	2	**3**	**4**
Non-corrected Perturbation	12%	27%	0%	18%	22%	23%	22%	25%	28%
Average Date of Peak	31-May	01-Jun	07-Jun	03-Jun	03-Jun	04-Jun	04-Jun	04-Jun	05-Jun
Standard Dev of Peak Date	23 days	35 days	8 days	11 days	9 days	11 days	15 days	17 days	19 days
Days>10,000 cfs	14	3	2	8	7	7	6	5	4
Days>8,000 cfs	23	8	10	19	17	16	15	13	11
Days>5,000 cfs	46	28	51	41	37	34	31	28	24
Days>2,500 cfs	82	67	90	69	62	58	53	48	43
Meets recommendation				yes	yes	yes	yes	no	no

Note: Bold values indicate recommendation not met. Baseline + 280,000 is water short 174,000 af in 1956; 83,000 af in 1957. Maximum years between meeting minimum conditions are computed at 97% of the target flow rate to account for differences between Bluff and Four Corners flows.

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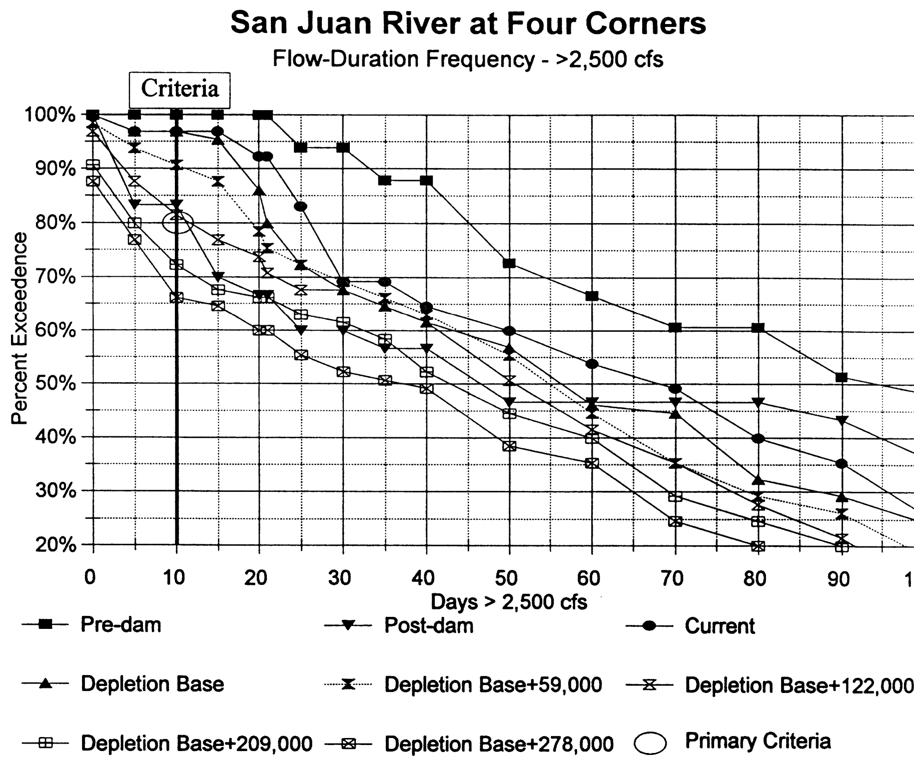

Figure 8.3. **Frequency/duration relationship for flows exceeding 2,500 cubic feet per second (cfs) with a peak release of 5,000 cfs.**

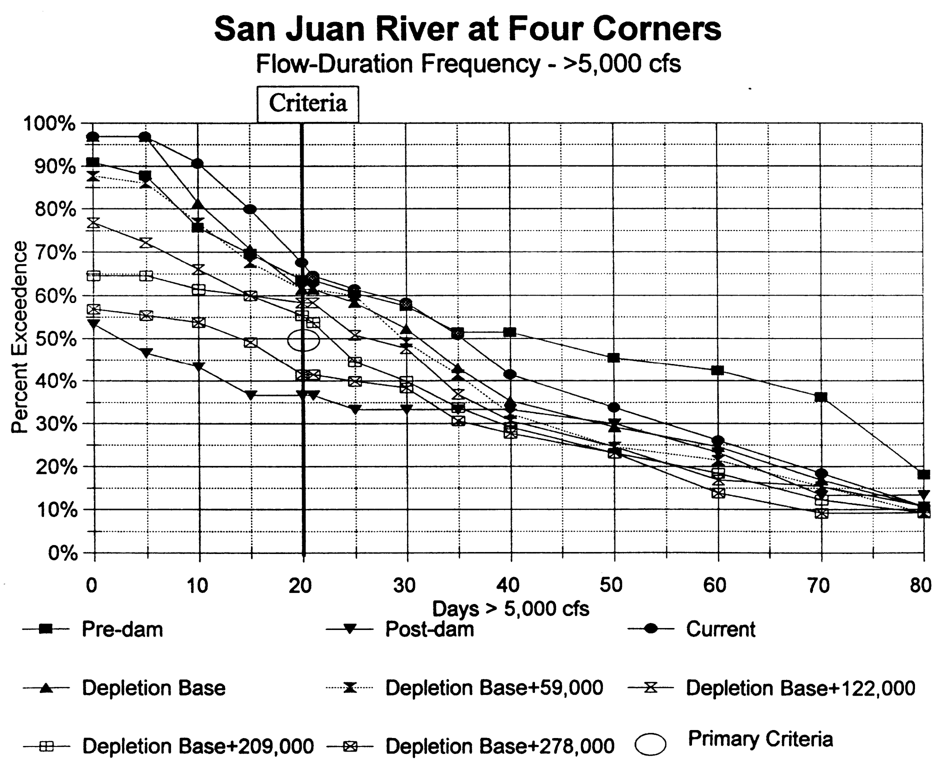

Figure 8.4. **Frequency/duration relationship for flows exceeding 5,000 cubic feet per second (cfs) with a peak release of 5,000 cfs.**

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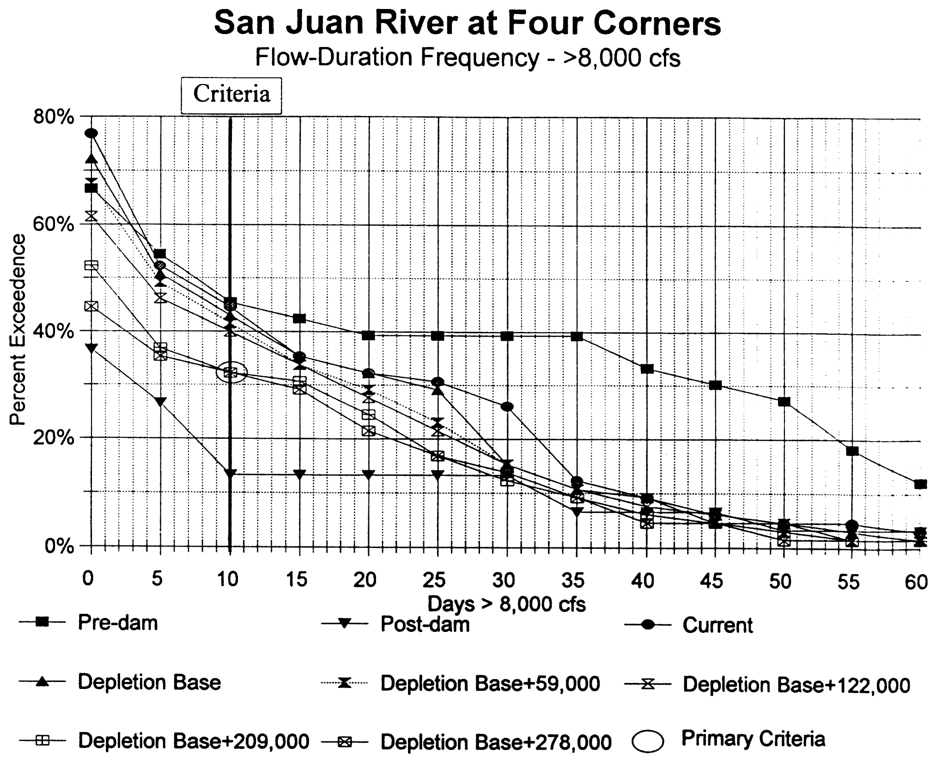

Figure 8.5. Frequency/duration relationship for flows exceeding 8,000 cubic feet per second (cfs) with a peak release of 5,000 cfs.

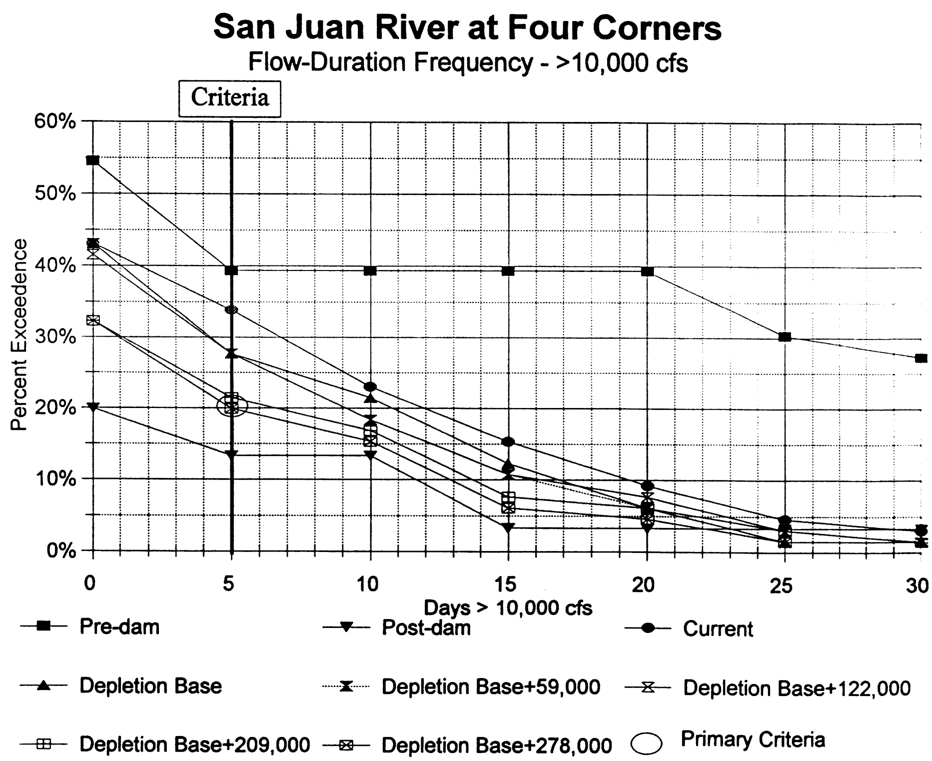

Figure 8.6. Frequency/duration relationship for flows exceeding 10,000 cubic feet per second (cfs) with a peak release of 5,000 cfs.

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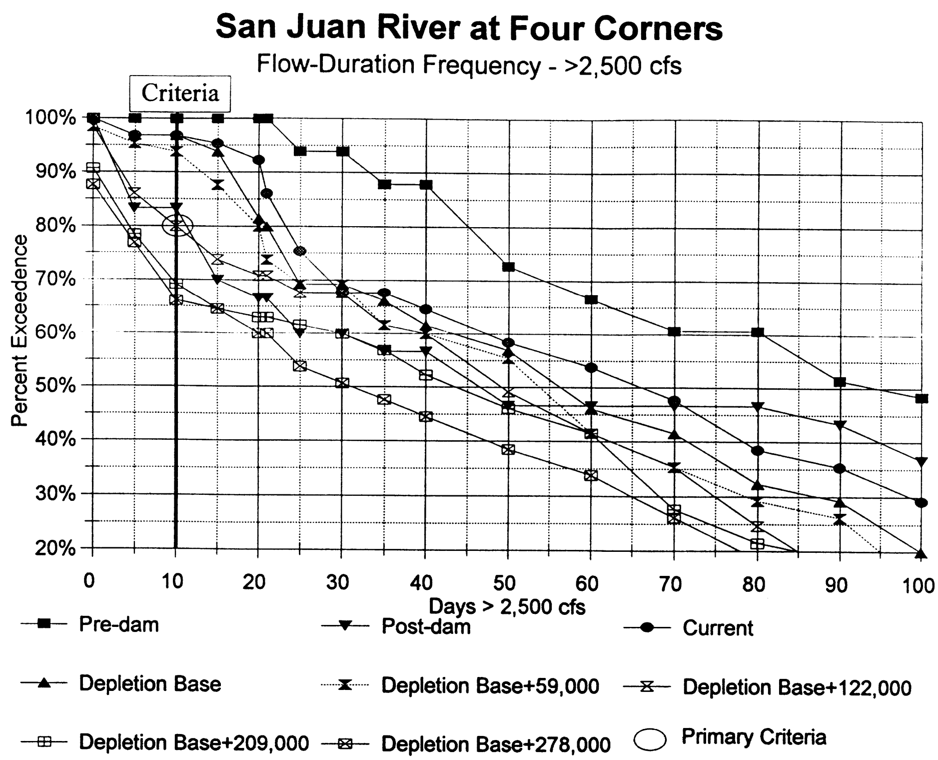

Figure 8.7. Frequency/duration relationship for flows exceeding 2,500 cubic feet per second (cfs) with a peak release of 6,000 cfs.

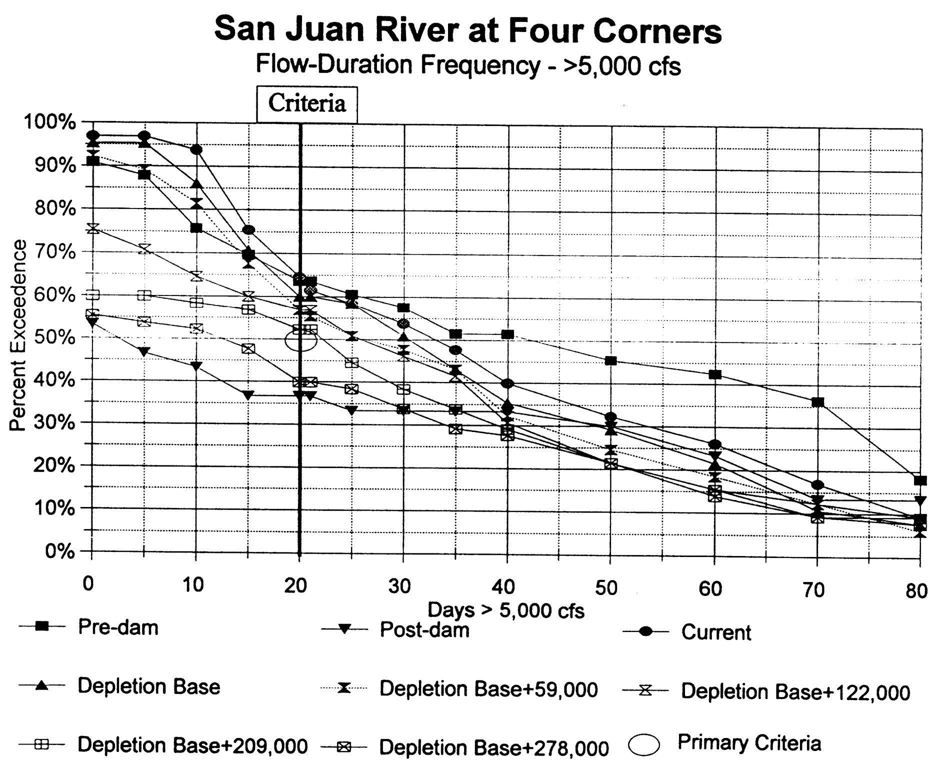

Figure 8.8. Frequency/duration relationship for flows exceeding 5,000 cubic feet per second (cfs) with a peak release of 6,000 cfs.

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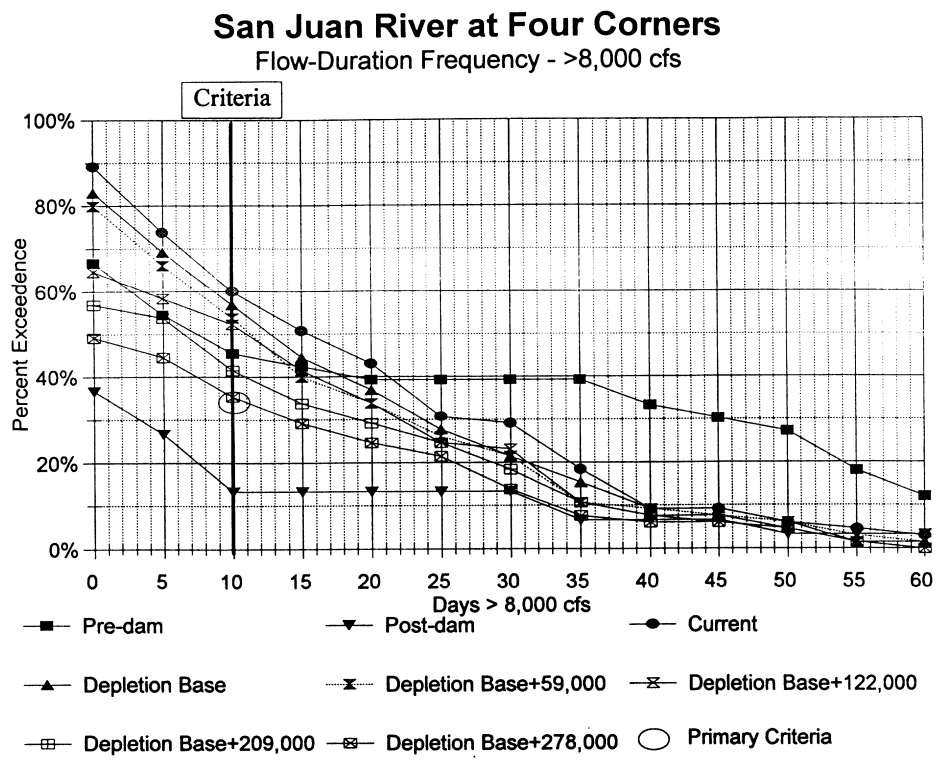

Figure 8.9. **Frequency/duration relationship for flows exceeding 8,000 cubic feet per second (cfs) with a peak release of 6,000 cfs.**

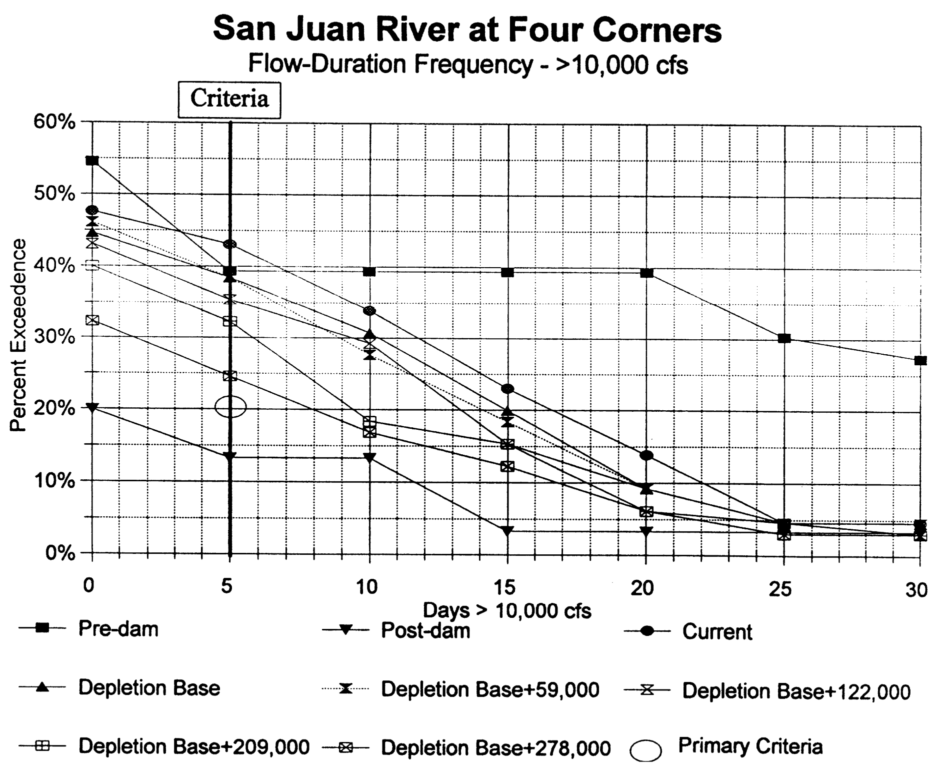

Figure 8.10. **Frequency/duration relationship for flows exceeding 10,000 cubic feet per second (cfs) with a peak release of 6,000 cfs.**

during this period. Because the dam is in place, the statistics for historical conditions without dam interference could only be assessed for this period by modeling the post-dam period to predict the conditions that would have occurred without the dam. Such modeling was not completed. Figures 8.11 through 8.18 show the time line of meeting the flow/duration criteria for each of the target flow levels listed above for 5,000 and 6,000-cfs peak release levels.

Another change in hydrograph statistics is in the average duration of flows above the target rates of 2,500, 5,000, 8,000, and 10,000 cfs. This reduction in average duration reflects the level of additional depletions from the system.

Backwater Habitat Results

The results of the flow/habitat model, applied to each of the model runs and historical periods, are shown in Table 8.7 for a peak release of 5,000 cfs and in Table 8.8 for a peak release of 6,000 cfs. The first two sets of values show average backwater area for late summer through early winter for Reaches 1 to 4 and 1 to 5. The second two sets show average area for peak runoff months after typical expected razorback sucker spawning for Reaches 1 to 4 and 1 to 5. The values reflect all conditions of the backwater model, including flow/habitat relationships and perturbation conditions. The backwater area in Reaches 1 to 4 is available to YOY spawned in Reach 5, where Colorado pikeminnow spawning presently occurs. If spawning could occur in Reach 6 through barrier removal and expansion of range, then the values for Reaches 1 to 5 would apply.

The worst conditions for backwater habitat occurred post-dam when habitat-flushing flows were limited and base flows were maintained in the range that produced the minimum backwater habitat. The average backwater area for Reaches 1 to 5 during the pre-dam period was 20.24 acres (ac), compared with the post-dam area for Reaches 1 to 4 of 11.07 ac. Since this was the only portion of the river available to young Colorado pikeminnow below a spawning area, Reaches 1 to 4 were used during the post-dam period, whereas Reach 5 and perhaps even Reaches 6 to 8 were available during the pre-dam period. This comparison of post-dam and pre-dam periods indicates there was at least a 45% loss of backwater habitat in the upper San Juan River. In addition, the creation of Lake Powell in the early 1970s at the other end of the San Juan River also resulted in the loss of potential backwater habitat, thus increasing the impact to YOY Colorado pikeminnow habitat.

Modeled backwater habitat area for levels of development through depletion base plus 122,000 af are better than those for the pre-dam period for the same range, because of better control over flows in the base-flow months.

Fish Recovery, Water Development, and Flow Recommendations

The recommended flow conditions can be met by applying the rules outlined in this chapter to the reoperation of Navajo Dam under current depletion levels and under some level of future development. The amount of future depletion that is possible while still meeting the conditions of the flow recommendations depends upon the magnitude, timing, and location of the depletion and the effect of these factors upon the operation of the entire river system. While the tools developed can analyze the impact of any collection of development projects on the ability of the system to meet

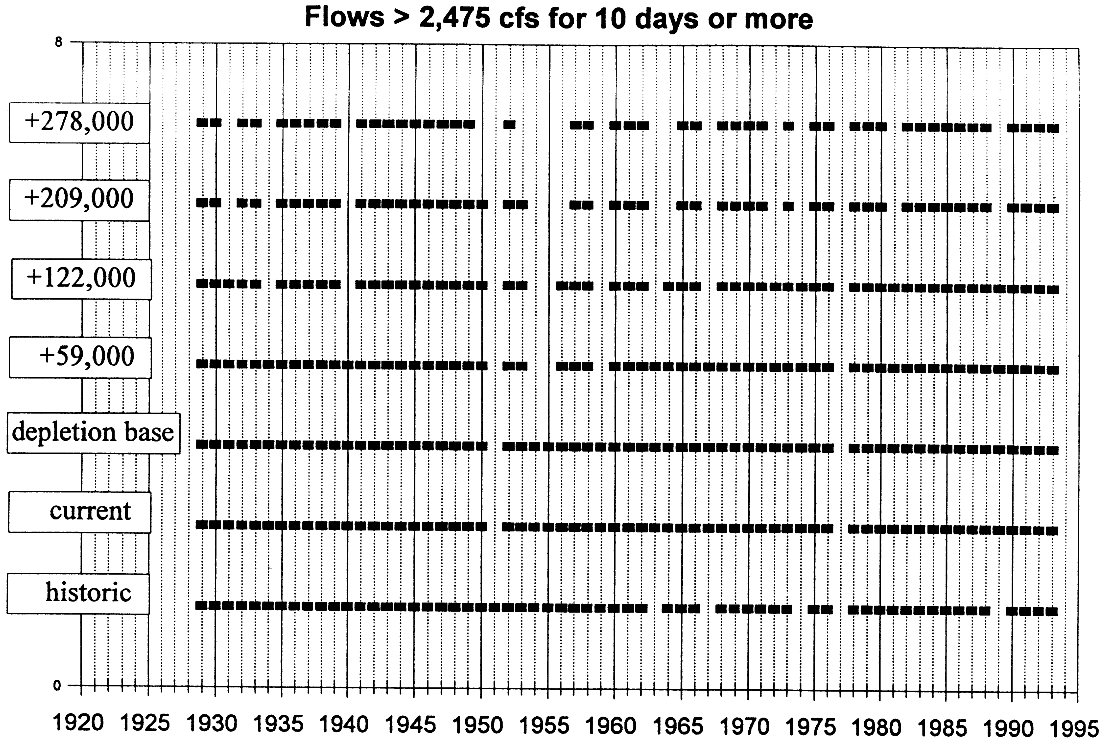

Figure 8.11. Time line for meeting minimum duration of flows > 2,475 cubic feet per second (cfs) (97% of 2,500) with a peak release of 5,000 cfs.

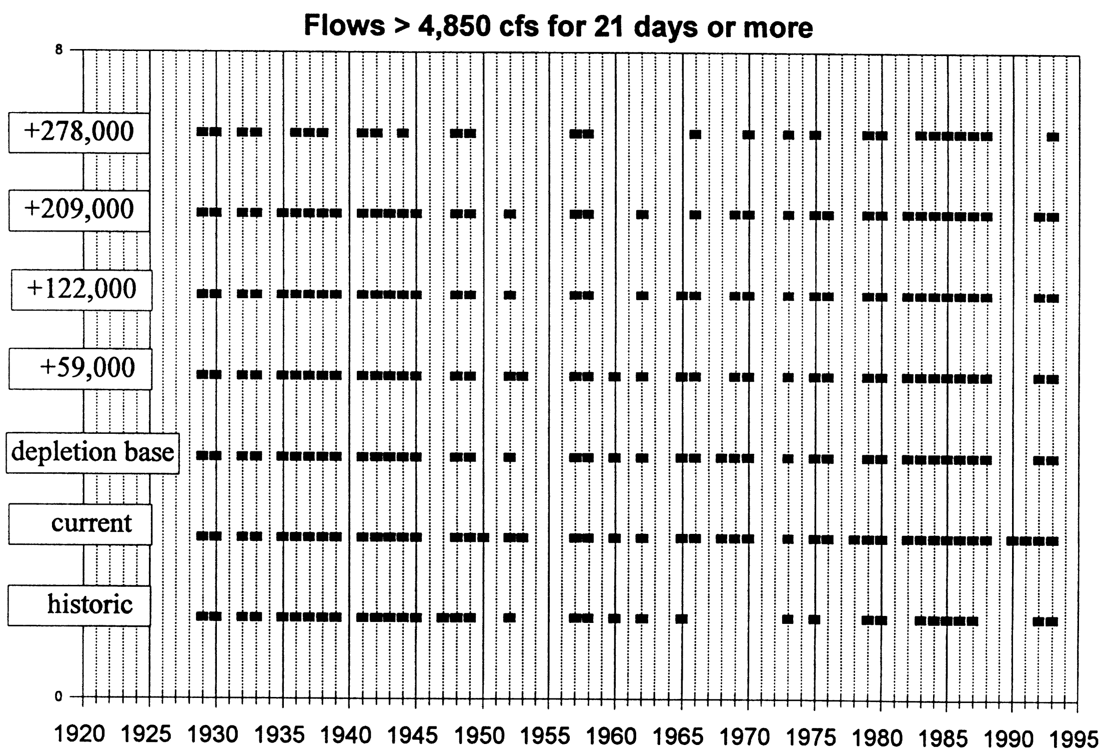

Figure 8.12. Time line for meeting minimum duration of flows > 4,850 cubic feet per second (cfs) (97% of 5,000) with a peak release of 5,000 cfs.

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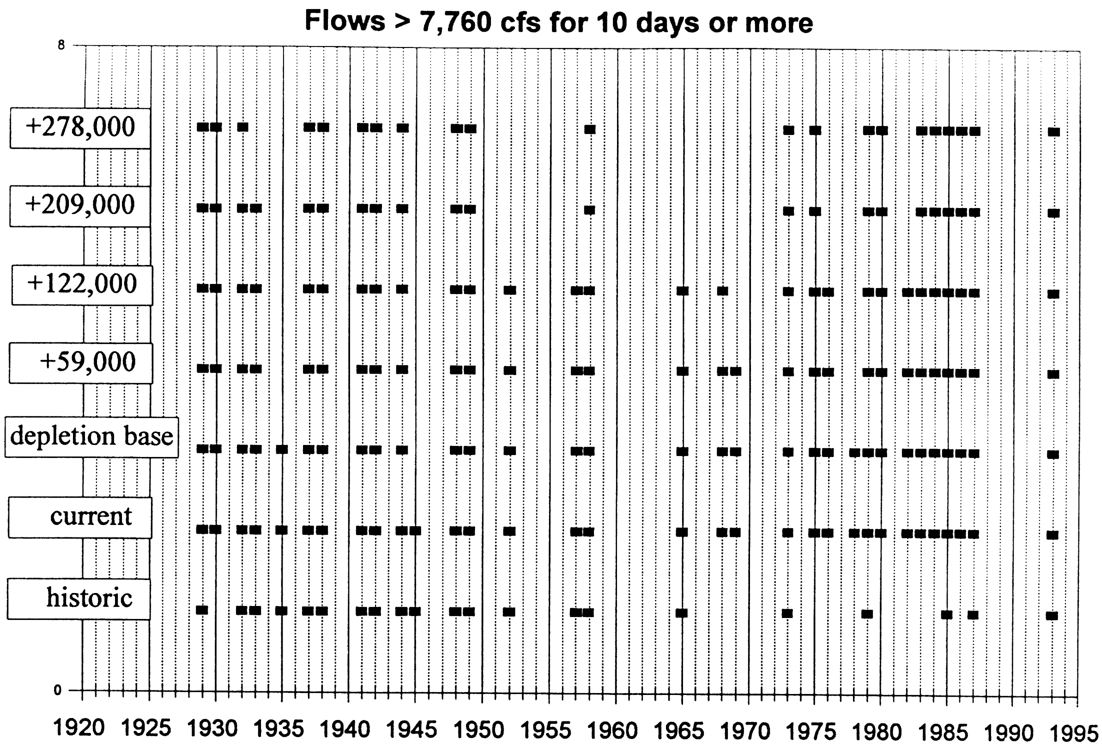

Figure 8.13. **Time line for meeting minimum duration of flows > 7,760 cubic feet per second (cfs) (97% of 8,000) with a peak release of 5,000 cfs.**

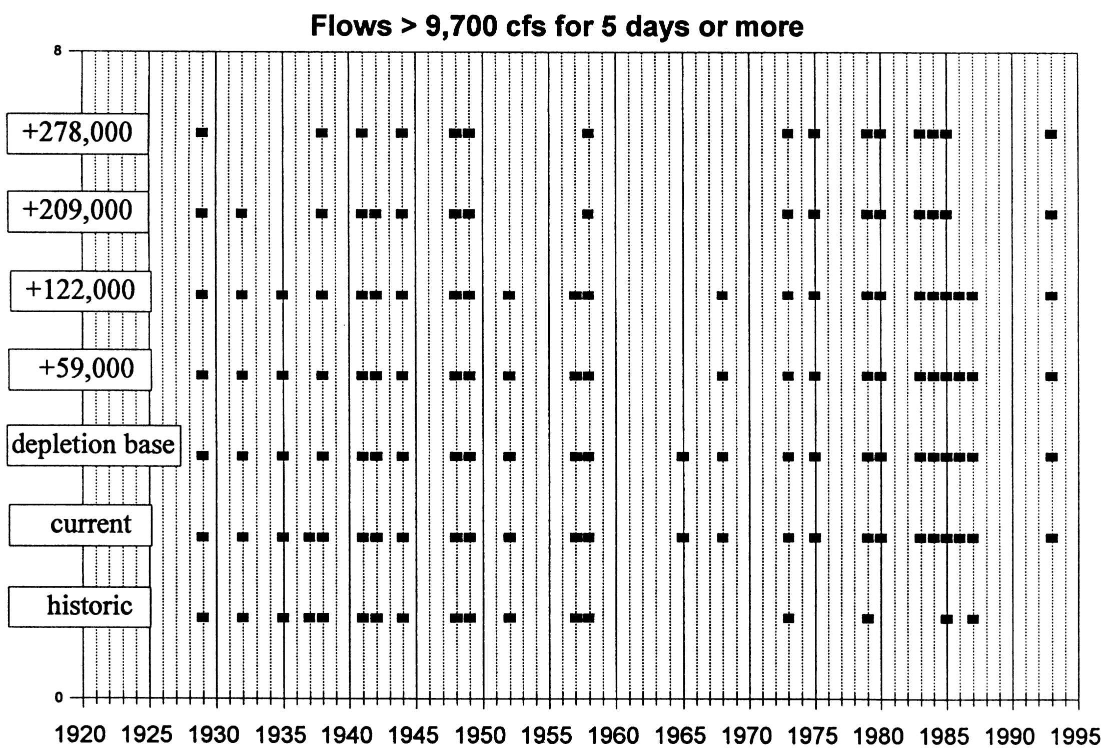

Figure 8.14. **Time line for meeting minimum duration of flows > 9,700 cubic feet per second (cfs) (97% of 10,000) with a peak release of 5,000 cfs.**

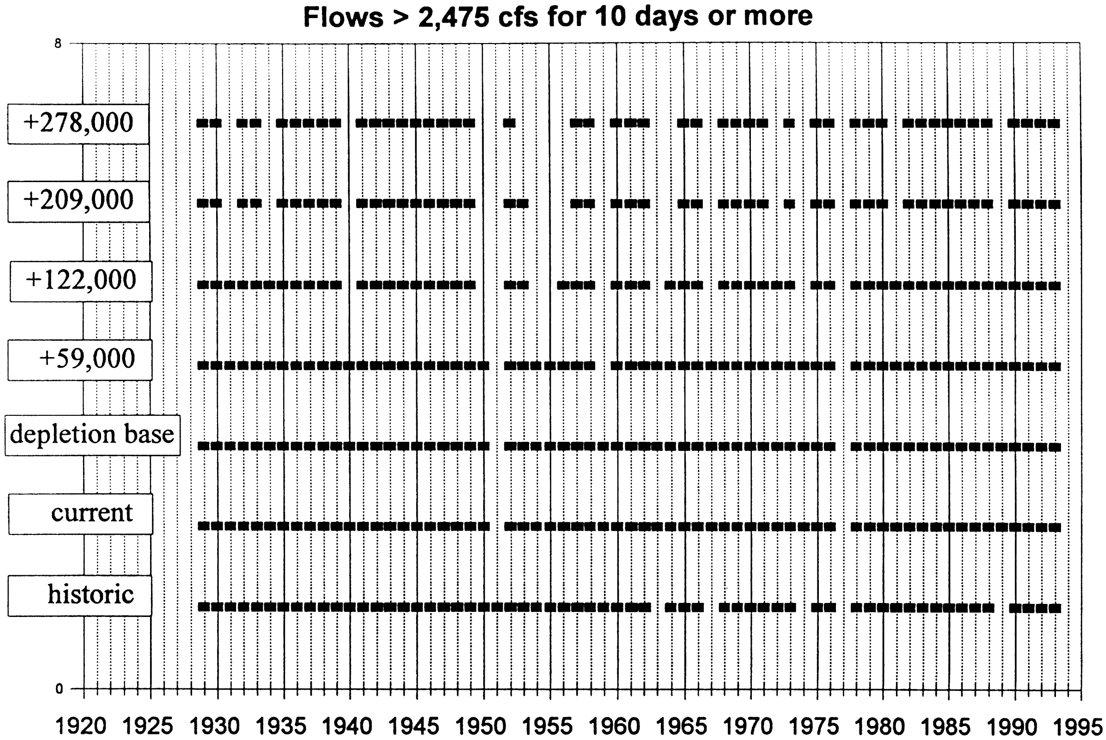

Figure 8.15. Time line for meeting minimum duration of flows > 2,475 cubic feet per second (cfs) (97% of 2,500) with a peak release of 6,000 cfs.

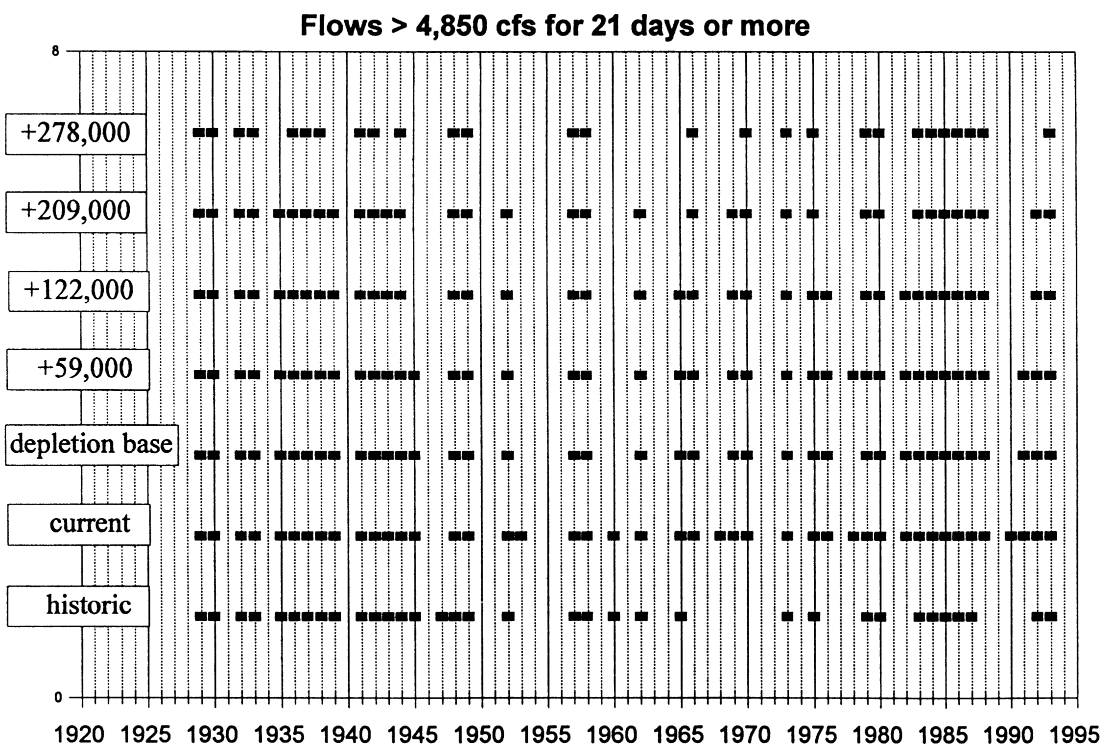

Figure 8.16. Time line for meeting minimum duration of flows > 4,850 cubic feet per second (cfs) (97% of 5,000) with a peak release of 6,000 cfs.

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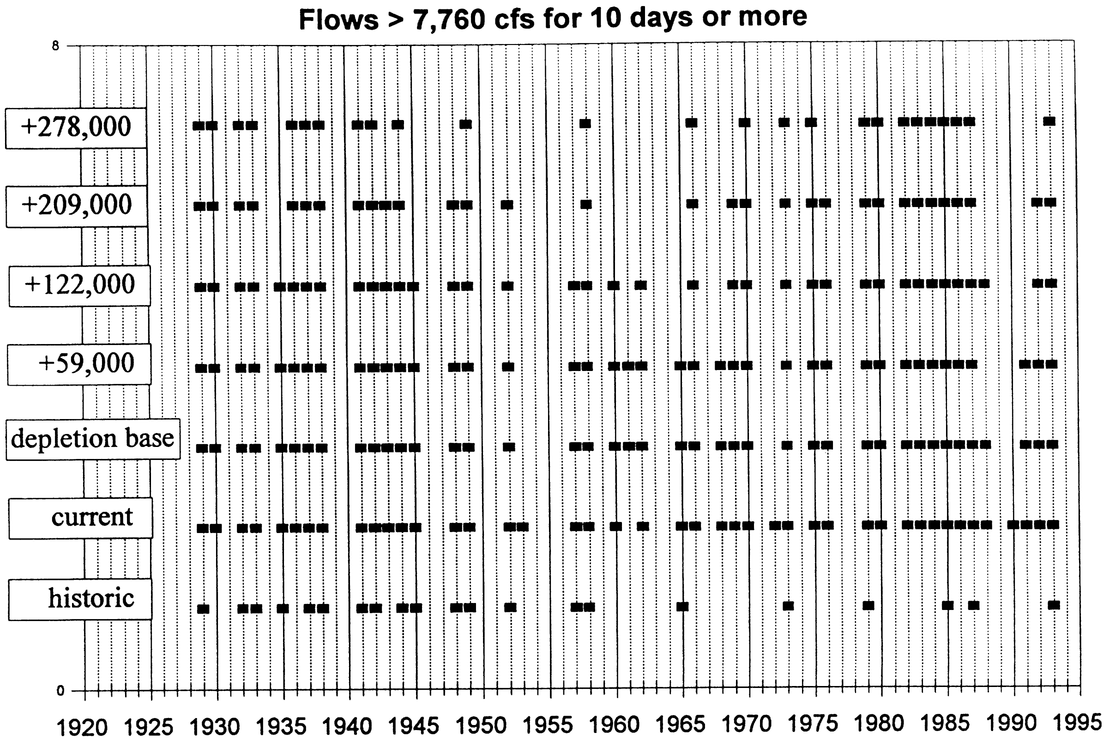

Figure 8.17. Time line for meeting minimum duration of flows > 7,760 cubic feet per second (cfs) (97% of 8,000) with a peak release of 6,000 cfs.

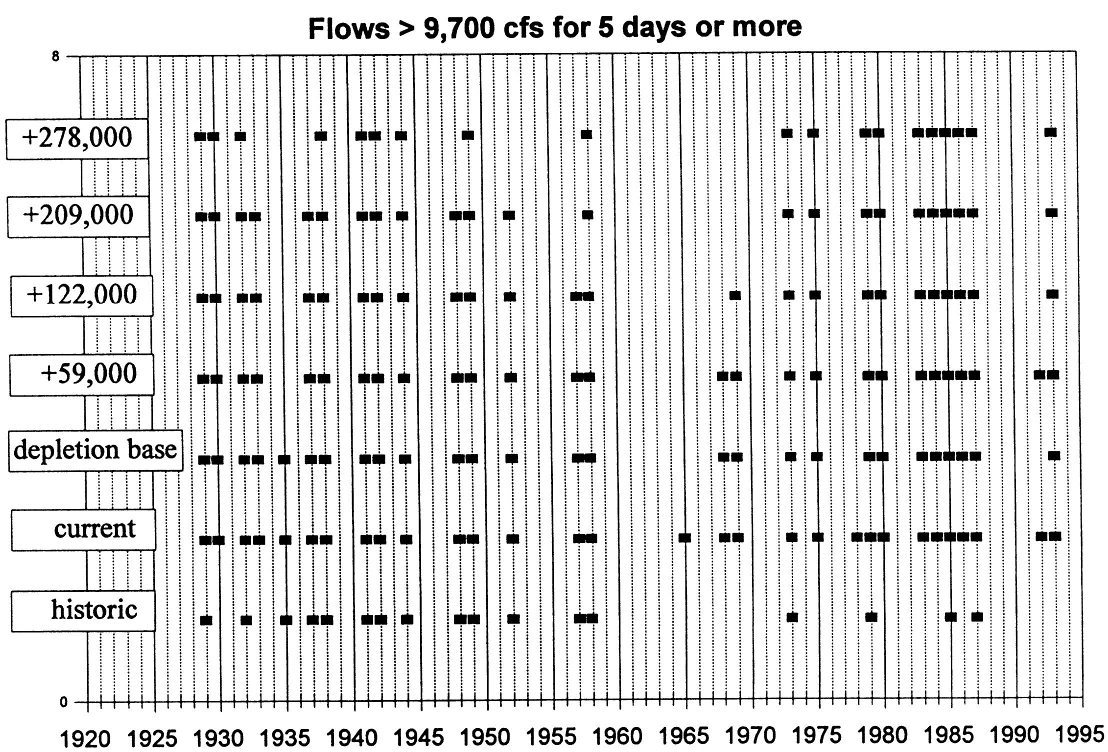

Figure 8.18. Time line for meeting minimum duration of flows > 9,700 cubic feet per second (cfs) (97% of 10,000) with a peak release of 6,000 cfs.

Table 8.7. Comparison of modeled backwater area for six levels of development and three historical periods with a peak release of 5,000 cfs.

PARAMETER	PRE-DAM	POST-DAM	STUDY PERIOD	CURRENT	DEPLETION BASE	BASE +59,000	BASE +122,000	BASE +210,000	BASE +280,000
Backwater availability, Reach 1-4 - acres									
Average before storms	21.32	14.34	23.05	23.53	24.16	23.68	22.69	21.71	20.22
August	16.94	11.89	17.69	18.65	19.19	18.73	18.14	17.51	16.36
September	14.92	11.69	15.22	17.08	17.66	17.14	16.50	15.52	14.49
October	13.75	10.46	14.61	16.16	16.76	16.33	15.52	14.91	14.15
November	14.78	11.04	14.10	16.26	16.74	16.39	15.72	14.98	14.02
December	15.92	10.29	15.66	15.61	16.28	16.05	15.63	14.67	13.73
Average (Aug-Dec)	15.26	11.07	15.46	16.75	17.33	16.93	16.30	15.52	14.55
Average Perturbation[a]	28%	23%	33%	29%	28%	29%	28%	29%	28%
Change from pre-dam		-27%	1%	10%	14%	11%	7%	2%	-5%
Backwater availability, Reach 1-5 - acres									
Average before storms	26.36	19.39	26.51	28.36	29.35	29.00	28.29	27.19	25.55
August	21.67	17.35	21.24	23.48	24.30	23.91	23.41	22.85	21.72
September	19.89	17.53	18.28	22.20	22.92	22.41	21.64	20.72	19.67
October	18.36	15.21	17.69	20.99	21.74	21.49	20.58	19.97	19.28
November	19.76	15.36	17.15	21.37	22.18	21.90	21.26	20.24	19.38
December	21.54	14.76	19.80	20.47	21.68	21.53	21.27	19.87	19.10
Average (Aug-Dec)	20.24	16.04	18.83	21.70	22.56	22.25	21.63	20.73	19.83
Average Perturbation[a]	23%	17%	29%	23%	23%	23%	24%	24%	22%
Change from pre-dam		-21%	-7%	7%	11%	10%	7%	2%	-2%
Razorback sucker backwater availability, Reach 1-4 - acres									
May	14.64	15.29	18.53	15.67	16.10	15.80	15.56	15.70	14.72
June	14.11	14.72	17.22	17.21	16.54	16.42	16.19	16.55	15.12
July	16.35	17.34	14.56	19.50	20.74	20.00	18.91	19.43	18.25
Razorback sucker backwater availability, Reach 1-5 - acres									
May	21.65	19.02	20.34	21.80	21.85	21.62	21.37	21.64	20.48
June	21.24	18.60	22.48	23.96	23.13	22.79	22.47	22.58	20.86
July	22.20	21.57	25.58	23.84	25.41	24.77	23.52	24.23	23.11

[a]Average loss in habitat area due to sediment laden storm events over the period of record computed as one minus the average habitat available for August-December divided by the average before storms.

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Table 8.8. Comparison of modeled backwater area for six levels of development and three historical periods with a peak release of 6,000 cfs.

PARAMETER	PRE-DAM	POST-DAM	RESEARCH PERIOD	CURRENT	DEPLETION BASE	BASE +59,000	BASE +122,000	BASE +210,000	BASE +280,000
Backwater availability, Reach 1-4 - acres									
Average before storms	21.32	14.34	23.05	23.72	24.31	24.09	22.67	20.88	19.96
August	16.94	11.89	17.69	18.79	19.26	19.11	18.05	16.88	16.10
September	14.92	11.69	15.22	17.14	17.75	17.55	16.32	14.91	14.19
October	13.75	10.46	14.61	16.26	16.85	16.55	15.48	14.37	13.96
November	14.78	11.04	14.10	16.40	16.82	16.74	15.47	14.40	13.85
December	15.92	10.29	15.66	15.95	16.47	16.49	15.60	14.12	13.60
Average (Aug-Dec)	15.26	11.07	15.46	16.91	17.43	17.29	16.23	14.93	14.34
Average Perturbation[a]	28%	23%	33%	29%	28%	28%	28%	29%	28%
Change from pre-dam		-27%	1%	11%	14%	13%	6%	-2%	-6%
Backwater availability, Reach 1-5 - acres									
Average before storms	26.36	19.39	26.51	28.65	29.54	29.41	28.21	26.25	25.24
August	21.67	17.35	21.24	23.70	24.31	24.40	23.29	22.22	21.35
September	19.89	17.53	18.28	22.20	23.03	22.86	21.49	20.06	19.36
October	18.36	15.21	17.69	21.00	21.95	21.64	20.52	19.33	19.05
November	19.76	15.36	17.15	21.64	22.22	22.31	21.18	19.61	19.11
December	21.54	14.76	19.80	21.00	21.90	21.98	21.25	19.42	18.96
Average (Aug-Dec)	20.24	16.04	18.83	21.91	22.68	22.64	21.55	20.13	19.56
Average Perturbation[a]	23%	17%	29%	24%	23%	23%	24%	23%	22%
Change from pre-dam		-21%	-7%	8%	12%	12%	6%	-1%	-3%
Razorback sucker backwater availability, Reach 1-4 - acres									
May	14.64	15.29	18.53	15.48	15.54	15.48	15.44	15.54	14.44
June	14.11	14.72	17.22	16.67	16.24	16.26	15.89	15.93	14.70
July	16.35	17.34	14.56	19.53	20.86	20.43	18.83	18.59	18.09
Razorback sucker backwater availability, Reach 1-5 - acres									
May	21.65	19.02	20.34	21.89	21.72	21.50	21.51	21.65	20.19
June	21.24	18.60	22.48	23.41	22.78	22.70	22.10	21.86	20.37
July	22.20	21.57	25.58	23.89	25.52	25.11	23.38	23.32	22.91

[a]Average loss in habitat area due to sediment laden storm events over the period of record computed as one minus the average habitat available for August-December divided by the average before storms.

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the flow requirements, they cannot provide an accounting of what is already "approved" for development and what would be considered as "future" development. The results reported in Chapters 7 and 8 discuss an approximation of what has been "approved" for development as the "depletion base." Since this depletion base has neither been reviewed and agreed upon by the SJRIP participants nor accepted by the responsible agencies, it stands only as an estimate of the level of depletion to which future projects must be added to determine impact. The "depletion base" should not be equated with the "Environmental Baseline" used in Consultations by the USFWS. It is only an unapproved estimate of that level of depletion.

With this clarification, the results of the modeling reported in this chapter indicate that the flow recommendations can be met when applying the suggested operating rules for all hypothetical development scenarios tested through depletion levels of "depletion base" plus 122,000 af. Hypothetical scenarios tested with depletion levels of 210,000 af and 280,000 af above "depletion base" were not able to meet the required flow conditions, and the development scenario with depletions of 280,000 af beyond "depletion base" experienced severe water shortages. These tests have been completed on specific hypothetical scenarios and have not assessed the ability of any specific project to meet the flow requirements, and they do not imply any specific order of priority of development. Further, they do not precisely define the level of allowable development, which is dependent upon the nature of the development as well as the volume of depletion. The tests were only completed to develop and optimize operating rules and analyze the relationship between levels of hypothetical water development and the ability to meet recommended flow requirements.

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